Glaciers such as this one, the Lyman glacier in the North Cascades, have been retreating for the past 50-150 years.

UNCERTAIN FUTURE

Changes in Snowpack and Stream Flow

Understanding how climate fluctuations affect the hydrologic cycle—the timing and amount of rain, snow, snow melt and stream flow—is fundamental to understanding climate impacts on Puget Sound.

These changes include:

- Reduced spring snowpack,
- Earlier spring snowmelt,
- Increased winter flow,
- Decreased summer flow.[15]

> *"Almost everywhere in the Cascades, snowpack has declined markedly since 1950."*

These changes, most of which have been linked by scientists to rising temperatures,[16] can lead to altered habitat for fish and other species. The observed changes also have implications for municipal and agricultural water supplies dependent on snowpack.

Snowpack and stream flow in the 20th century

Across much of the western United States, scientists have observed hydrologic changes in the past 50 years that are consistent with the observed atmospheric warming.

The hydrologic changes found throughout the West have also been observed in Puget Sound. Snowpack measurements (depth of water from melted snow, also known as the snow water equivalent or SWE) on April 1 (the most common date for observations and roughly the date of peak snowpack) show that SWE has declined markedly almost everywhere in the

Cascades since 1950.[17] These declines exceeded 25 percent at most locations, and tended to be largest at lower elevations. Compare, for example, the large decline of 33 percent observed at Tunnel Avenue (elevation 2450 feet, or 747 m) and the small decline of 4.5 percent at Rainy Pass (elevation 4780 feet, or 1457 m) (Figure 1). The trends show warming is clearly playing a role in these declines.

Freshwater inflow to Puget Sound—the total flow of all of the major rivers[18]—is an important characteristic of the Sound's marine environment. The seasonality of input and the timing and magnitude of winter and spring high-flow events influence water temperature, salinity, circulation patterns, habitat characteristics and marine life.

Freshwater inflow has changed over the period 1948-2003 in the following ways:

(a) Total annual inflow declined 13 percent owing to changes in precipitation,

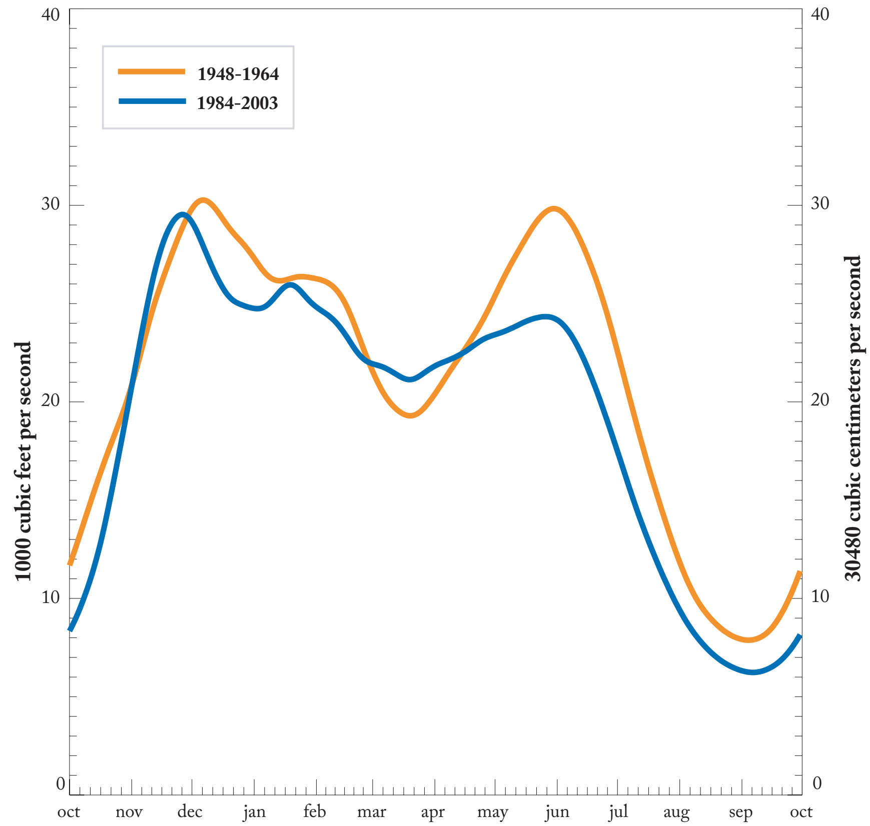
(b) The timing[19] of snowmelt shifted earlier by 12 days, or 2.1 days per decade (Figure 4),

(c) The fraction of annual flow entering Puget Sound during the summer months (between June and September) decreased 18 percent,

(d) The likelihood of unusually high daily inflow increased, despite the decline in annual inflow,

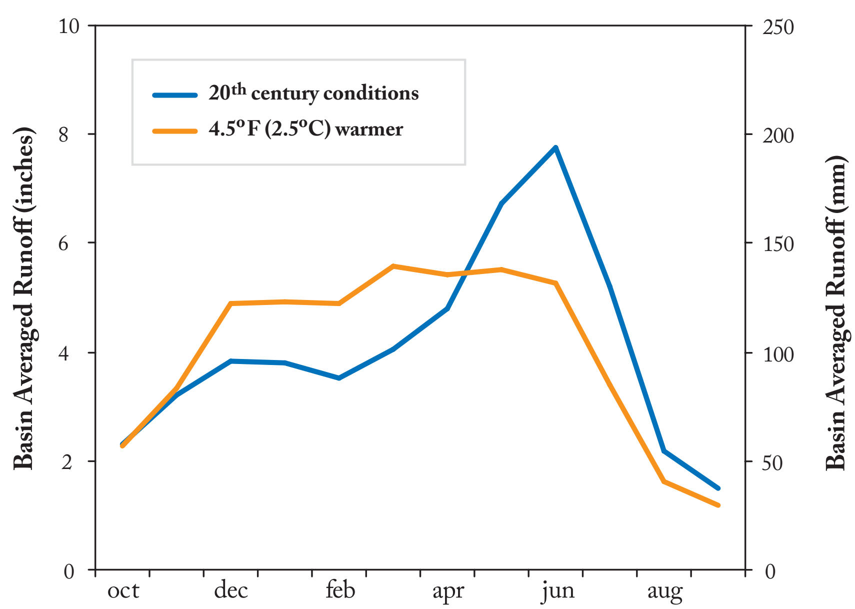
(e) The likelihood of unusually low daily inflow increased.[20]

Although it is impossible to attribute these changes specifically to global warming, and land use and flow regulation may play a role in these observed changes, it is important to note that all of these changes (except (a) which may be associated with PDO effects) are consistent with warming.[21]



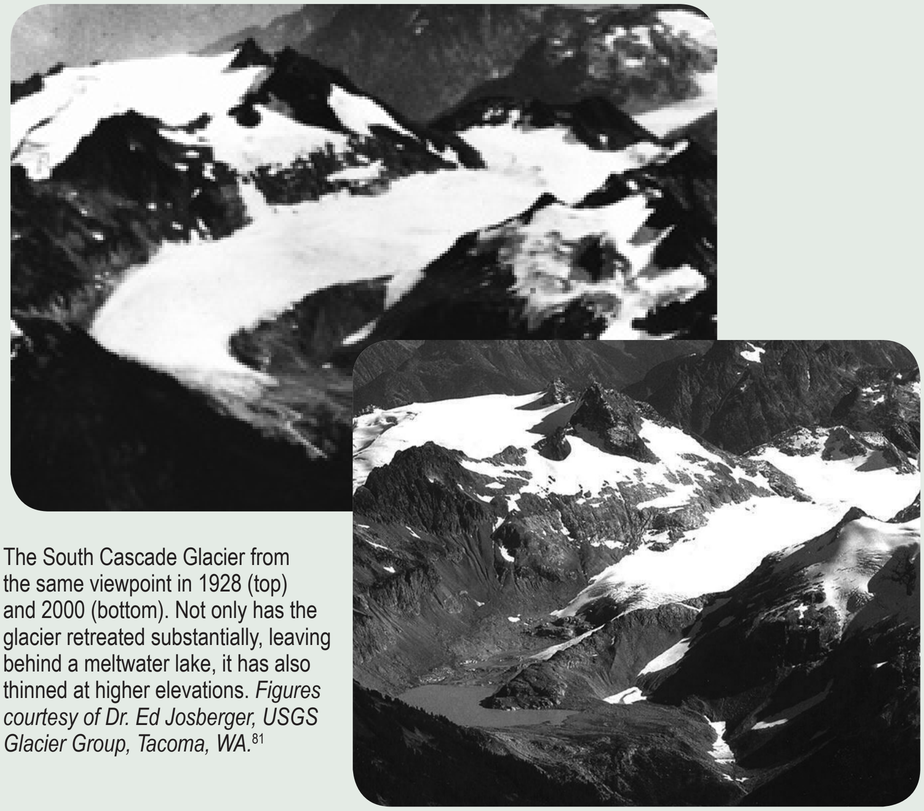
Average Daily Freshwater Flow into Puget Sound

Figure 3: Average daily freshwater flow into Puget Sound (found by adding the flow of nine of the largest rivers) for 1948-1964 (orange) and 1984-2003 (blue). Note the decline in May-October and increase in March-April.



Simulated Average Runoff for the Puget Sound Basin

Figure 4: Simulated average runoff for the Puget Sound basin, for 20th century climate (blue) and for a warming of +4.5°F (+2.5°C) (orange), which could occur as early as the 2040s but probably not until later in the century. Note the projected declining summer flow, which matches observed changes (Figure 3).



The South Cascade Glacier from the same viewpoint in 1928 (top) and 2000 (bottom). Not only has the glacier retreated substantially, leaving behind a meltwater lake, it has also thinned at higher elevations. *Figures courtesy of Dr. Ed Josberger, USGS Glacier Group, Tacoma, WA.*[81]

"Nearly every glacier in the Cascades and Olympics has retreated during the past 50–150 years in response to warming."

Glaciers in retreat

Nearly every glacier in the Cascades and Olympics has retreated during the past 50-150 years in response to warming.[21]

Small glaciers are disappearing rapidly, and glacial mass is being reduced on the larger ones. While the total water input into Puget Sound from melting glaciers is minimal, glacial retreat can have important local effects.

In higher reaches of certain river basins (such as the Nooksack) and some tributaries to the Skagit, melting glaciers provide a substantial portion of stream flow in late summer. This is also true for the Nisqually River, which is fed by receeding glaciers on Mt. Rainer.

Glaciers also have significant local effects on stream temperature and water supply for aquatic plants and animals. Significant reductions in glacial input to streams would dramatically alter vulnerable aquatic habitat.

Snowpack and stream flow in the 21st century

The seasonal timing of freshwater inflows to Puget Sound is extremely sensitive to temperature. The primary consequences of regional warming scenarios are:[23]

- Reduced winter snowpack in the mountain portions of the basin,
- Greater stream flow in winter (more precipitation falling as rain and less as snow),
- Earlier occurrence of peak runoff,
- Reduced summer flows.

For a warming of +4.1˚F (+2.3˚C), which could occur as early as the 2040s (but probably not until later in the century), October through March runoff increases by about 25 percent and April through September runoff decreases by 21 percent (Figure 4). The consequences of these changes for Puget Sound circulation and ecosystems are described in the following sections.

Flooding

Higher winter temperatures are likely to increase the chance of flooding in Puget Sound as more winter precipitation falls as rain rather than snow in moderate elevation mountain areas, such as the Cascades.[24] If winter precipitation increases, as some models suggest, the risk of flooding would be compounded.

Flooding increases in free-flowing rivers are a concern because management of high flows is not an option. In managed systems high stream flows can be controlled to a certain extent. Most urban areas located on river mouths are partially protected by upstream flood-control reservoirs or were developed sufficiently far above the waterline to protect against flooding. Agricultural districts in river deltas (such as the Skagit) are partly protected by dikes. However, increases in natural flows could still cause increased flooding in managed systems when these protective measures are overwhelmed.

Western Washington is famous for its rain. With a warmer climate, however, scientists believe more of our precipitation will fall as rain rather than as snow at higher elevations. That means a higher chance of flooding and other problems associated with more freshwater entering salty Puget Sound.